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XXXVI. *New Experiments and Observations
concerning Electricity; by Robert Symmer,
Esq; F. R. S.*

P A P E R I.

Of the Electricity of the human Body, and the Animal Substances, Silk and Wool.

Read Feb. 1. 1759. **I** had for some time observed, that upon pulling off my stockings in an evening they frequently made a crackling or snapping noise; and in the dark I could perceive them to emit sparks of fire. I made no doubt but that this proceeded from a principle of electricity; and I was confirmed in this opinion, by observing that, in weather favourable for electrical experiments, those appearances were more remarkable than at other times. I mentioned this observation to several of my friends, and some of them told me, they likewise had often perceived the snapping, and the emission of fire from their stockings upon pulling them off, especially in the winter evenings: but I could not hear of any body that had taken this phenomenon into consideration in a philosophical way. For my own part, I could not but think that so striking an appearance, one that seems to have an immediate connexion with the human body, or is at least as much about us as the cloaths we wear, and is obvious to the perception of our senses, merited not only a philosophical attention, but the strictest inquiry possible. I was the more in-

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duced to such an inquiry, as it seemed to me to open a new path for proceeding in electrical researches, and might perhaps throw new light on the great and surprising discoveries already made in that branch of natural philosophy. The simplicity of the apparatus, and the great facility in making the proper experiments, putting it in my power to begin and carry on my enquiry at pleasure, I entered upon somewhat of a regular course of observations about the beginning of November last; and since that time have pursued it as closely as my leisure, and the weather, which has been far from favourable for electrical experiments, would permit. It is the purpose of this, and of those papers that may follow, to lay before the Royal Society an account of the experiments and observations I have already made, or may hereafter be able to make, in the progress of this inquiry.

My first endeavour was to discover what sort of stockings was most proper to produce electricity. In order to determine this, I tried single stockings of different kinds, *viz.* thread, cotton, silk, and worsted, putting them on, and wearing them some time. On pulling them off, I could perceive nothing of electricity in the thread or cotton, and no remarkable degree of it in the silk and worsted.

When I say *no remarkable degree of it*, it may be proper to be a little more explicit. I must therefore observe, that silk and worsted, being in themselves electric, are both of them, especially silk, extremely susceptible of electricity. I have sometimes observed, particularly when the weather was favourable, that silk, when but barely handled, nay, when but simply touched, has become electrical where it had been handled

handled or touched, as appeared by its attracting little light balls suspended by threads. It cannot therefore be supposed that silk or worsted stockings can be put upon the leg, without being excited to a sensible degree of electricity. And thence it is, that when taken off they are sometimes perceived to snap, though worn single. But whatever electricity the single stocking acquires by friction or otherwise, it immediately loses upon being separated from the leg: if any electric virtue remains, it is no more than what belongs to it as an electric substance ceasing to be excited; and it is in so small a degree, as in the present case not to merit attention. In general, when I speak of the electricity in question, I mean such a power of electricity as is obvious, and perceptible to the senses; so that the stocking, after being taken off, should appear more or less inflated; throw out an electrical wind to be felt by the bare leg; attract or repel another stocking visibly; and, upon the touch, snap, and emit, or receive electrical fire.

After making the experiment above-mentioned with single stockings, I proceeded to try the effect of two stockings upon one leg. This I did with two of thread, cotton, worsted, and silk successively; but this produced no electrical appearance more than before. I then combined them one with another, and, running through all the different changes, I found that none of those I then made use of exhibited visible proofs of electricity, but the silk and worsted together; and there, indeed, the electric power appeared remarkably strong. It seemed to be a matter of indifference whether the silk or the worsted was uppermost, the combination of the two was what I judged

judged to be essential; and happening at that time to wear silk stockings with thin worsted under them, I kept to the use of these, and found it a convenient circumstance in the course of my experiments.

As some may have the curiosity to examine the observations I present them with, by experiments of their own making; before I proceed further, I shall furnish them with a few remarks, which may enable them to make their experiments with more ease and certainty, than if they set out unacquainted with some circumstances, which I have learnt from experience.

One of the first things to be attended to, is the weather, which has an influence on all electrical experiments, but upon none more than those which relate to this branch of electricity. The most favourable weather is that which is dry and clear, and, if a little frosty, so much the better. In general, when the quicksilver in the barometer rises, and the fire burns remarkably brisk and clear, we may expect a considerable appearance of electricity: at other times, it is better not to attempt the experiment.

When the weather is favourable, it is not necessary to wear the stockings all day: That, indeed, raises the electrical power to the highest degree; yet, provided they be dry, and made warm by the fire, before they are put upon the leg, their continuance upon it for a very short time, prepares them sufficiently for exhibiting visible proofs of electricity. If this should not answer upon the first trial, the operation may be repeated two or three times, to bring them into a proper disposition to receive the electrical virtue; and this is no more than what is found to be sometimes
necessary

necessary with respect to glass globes and tubes, especially when new. If the stockings have once acquired this disposition, they retain it for the day, or until a change of weather, and the experiment may be repeated with success as often as one pleases; for no sooner are they discharged of their electricity, than they are ready to receive it anew; nay, if speedily returned upon the leg, they catch it instantaneously, and may immediately be pulled off to exhibit a new explosion: what is still more surprising, they seem to gather force by the frequency of the repetition, and, to some certain degree, increase in electrical power, provided they be all along kept warm and dry, and that the leg continue warm.

Another circumstance to be carefully attended to, is the manner in which they are to be taken off; for as to the putting of them on, it is a matter of indifference how that is performed. In taking them off, care must be had not to separate them; for if that happens in pulling them off, all the electricity escapes. The best way, is to put the hand between the leg and the stockings, and push them off together. Nothing more remains to be done, than to pull them asunder; for upon that, they both of them exhibit a degree of electricity, which, when at the highest, is really surprising.

Before I conclude these occasional remarks, it may not be improper to observe, that it is not absolutely necessary that the stockings be applied to the bare leg; if a fine thread stocking separate them from the leg, though left upon it when they are taken off, it does not much impair their electricity. But it is more convenient to use the hand instead of the leg. The
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insertion of the hand into the stockings, is alone sufficient, especially in favourable weather, to communicate such an electric power, as renders them capable of answering expectation, in such experiments as I have had occasion to make*.—I now return to my subject.

The opinion I had conceived, that the combination of silk and worsted was necessary for the production of electricity, seemed to meet with confirmation from all the experiments I made with the stockings I then wore. I was at that time in mourning, so that my silk stockings were black, and under them I constantly wore thin white worsted. About the latter end of November I went out of mourning, and of course changed the colour of my stockings. On the second of December, having put on a pair of white silk above the worsted, after I had wore them some hours, I resolved to amuse myself with a few experiments. The weather was remarkably favourable, and I had reason to expect a fine appearance of electricity: but upon taking off my stockings, and pulling them asunder, to my great astonishment, I found they discovered no signs of electrical power; as I

* An improvement may perhaps be made upon this, by getting a piece of silk or worsted knit, or wove in the stocking loom, so that without being cut, it may be formed into the shape of long mittens or sleeves, or rather into what we might call a silk or worsted tube. The reason why it ought to be knit, or wove in the stocking loom, is, that it may better embrace the hand or arm; and likewise, that it may be more retentive of electric virtue, which would escape more easily from a piece of silk or worsted wove in the common loom, and cut with a number of ends of threads exposed, than from any thing formed in the fashion of chain work, and consisting of one single thread of silk or worsted.

held them in my hands they hung down collapsed, and did not more attract one another, than before they were put upon my leg. I repeated the experiment two or three times, but with no better success. An event I so little expected, disconcerted me much. I saw I was no longer to ascribe electricity to the combination of silk and worsted; but I remained at a loss to know to what I *should* ascribe it. At last, upon considering the circumstances of this and other experiments, a conjecture occurred, that the electricity in question might depend upon the nature of different colours. In order to determine this, I thought it fairest to make the trial in the same substances. Accordingly I had recourse to the following experiment.

I took a pair of white silk stockings, and having warmed them at the fire put them both upon the same leg. After I had worn them about ten minutes, I took them off, and pulled them asunder, but discovered no signs of electricity in either. I did the same with a pair of black silk, but to no other effect. I then proceeded to the decisive trial. I put a black and a white stocking upon my leg, and wore them likewise ten minutes. I waited with some impatience to see the success of my experiment, and in return had the satisfaction of observing, upon their being pulled asunder, that each of them had acquired a stronger degree of electricity than I had before seen: they were inflated so much, that each of them shewed the entire shape of the leg, and at the distance of a foot and a half they rushed to meet each other. I went through the same experiment with worsted stockings, and found that, as in silk, nothing but the combination of black and white produced electricity.

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As I had often experienced the power of electricity in the combination of black silk with white worsted stockings, there remained to try but that of white silk with black worsted, which answered as I expected, and seemed to complete the demonstration.

A phenomenon so new, and of so curious a nature as this experiment presented, could not but for some time engage my attention. I saw, that if this appearance did not arise from some accidental or collateral cause, correspondent effects would follow, upon the combinations of the intermediate degrees of light and shade, between the extremes of white and black. I have had a particular attention to this in the experiments I have since had occasion to make, and so far as I have yet been able to go, it appears to answer my expectation. Nevertheless, as this is a matter that merits a more minute examination, we may hereafter take it up as an immediate object of inquiry; with a view to determine, if light and colours have, of their own nature, a relation with electricity, and in what that relation consists.

In the mean while I shall pursue my principal design, which is to investigate from experiments the nature of that electric virtue, with which the animal substances under consideration appear to be endued. I have already made some progress, farther than what is contained in this paper; and I shall continue to follow the views that seem naturally to open to my inquiry. If I make any discoveries, or come at any conclusions that may merit the attention of the curious, they shall, together with the experiments on which they depend, be submitted to the judgment of this learned Society.

New Experiments and Observations concerning Electricity.

P A P E R II.

Of the Electricity of black and white Silk.

Read May 17, 1759. **I**N my former paper, I gave the Society an account of some experiments, made with silk and worsted stockings; by which it appeared, that the remarkable degree of electricity they had acquired, by being put upon the leg, depended on their being of different colours, namely, black and white. I did not then, nor do I yet, take upon me to determine the cause of this phenomenon. Whether it be owing to light, which is the origin of colours; or only to the ingredients, which enter into the composition of the several dyes; or to those conjunctly with the colours they produce: in any of these views the matter is curious, and equally merits a careful inquiry.—But I fear the solution of this, and of many other difficult questions concerning electricity, will depend upon the establishment of a more perfect theory than we have yet attained to. Till we shall be so fortunate as to discover the nature and properties of the powers employed in these operations, we must be satisfied to pursue the path of experiment and observation, in quest of those, as first principles. This is the method I shall continue to follow; and having already shewn the manner of electrifying the black and the white stocking, it is now my purpose to give an account of the appearances and powers of that electricity so excited.

Having made a great number of experiments since I had the honour of presenting my former paper to the Society, I have had an opportunity of observing, that the electricity produced between black and white silk, is stronger than that between silk and worsted of those different colours, and a great deal stronger than that between worsted and worsted: the last is so weak, except in time of frost, or when a sharp north-east wind blows, that tho' the effects are always of the same nature, yet they are sometimes so languid as to be scarce perceptible. I shall therefore, and for the sake of brevity, confine myself, in this paper, to what is observable with regard to the electricity between black and white silk.

It is proper to mention another circumstance: having found it troublesome to electrify the stockings, by putting them as often on my leg as was requisite in making experiments, I have quitted that method intirely; and satisfy myself with the degree of electricity which is excited in the stockings by drawing them upon the hand: and this is to be understood with regard to all the experiments and observations I may have occasion to mention, unless when otherwise expressed. The electricity thus produced is not equally powerful with that which is excited by means of the leg; but it is nevertheless sufficiently strong to answer all the purposes in view; and it is attended with this advantage, that the stockings continue longer fit for these experiments: for, like other electrical apparatus's, they must be kept clean, and free from all extraneous matter; and are therefore most to be depended upon when new, or when newly washed.

To give a distinct account of the electricity of black and white silk, I shall trace it through its whole process, beginning before the stockings of the different colours are put together.

After being a little air'd at the fire, when the black silk is drawn single upon the hand, a crackling noise is heard; and in the dark, sparks of fire may be perceived as passing between the hand and the stocking: while it is drawn backwards and forwards the crackling continues, and is most considerable upon the separation of the stocking from the hand. Thus it appears, that black silk is highly susceptible of electricity; that it is produced almost instantaneously, or at least with very little friction; that most of it escapes, while the stocking is yet upon the hand; and that, upon the total separation, very little remains. This is similar to what happens with the glass tube, when the hand, after passing along it in one direction, repasses it in the other. But still the electricity that the stocking retains, after it is separated from the hand, is considerable enough to attract or repel little light bodies at the distance of one or two feet: some degree of inflation in the stocking is likewise perceivable; and when a non-electric is brought near it, a crackling is heard, and in the dark sparks may be seen. If two black stockings be drawn upon the hand at a time, the appearances are much the same as before; only that the stockings, when taken off and separated, give smaller proofs of electricity, than if each of them had been single upon the hand.

Having found it necessary, as I proceeded in my course of experiments, to fix upon some method of ascertaining the principal appearances of electricity,
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and marking the degree of it, I had recourse to the little pocket electrometer of Mr. Canton's contrivance, which is described in Vol. XLVIII. N^o. 93. of the Transactions of this Society. When this instrument is supported by glass, it not only shews the attraction and repulsion, in general, of electrified bodies, which is one of the most essential properties of electricity, but it distinguishes between the positive and negative state of electricity, according to the reciprocal attraction or repulsion of the little balls. By the terms *positive* and *negative*, I mean only to denote the opposition of the two different states. The particular allotment of the one or the other term appears to me to be arbitrary; but that I may not differ unnecessarily from others, I shall apply the word *positive* to that state, in which a body is found to be, when electrified by the clear glass tube, rubbed by the hand; and the word *negative*, when electrified by the rough or opaque glass tube, of Mr. Canton's invention (described in the Transaction mentioned above), when rubbed in the same manner, or by sulphur or wax excited. In other words, when the body is in a state of repulsion with the former of those tubes, we say it is *positively* electrified, and *negatively* when in a state of repulsion with the latter, or with sulphur or wax.

Nothing appears to be more wonderful than this double state: here electricity seems to counteract itself, the electrified body attracting in the one, what it would repel in the other case, and *vice versa*. As this remarkable property may be traced, in its consequences, through almost all electrical appearances, I cannot but think it merits great attention, and, when
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it comes to be better understood, may throw much light upon the system of electricity. However that may be, it was impossible for me not to observe, that it runs through the whole of that branch, which I have at present under examination, and to which I return.

White silk differs much in electricity from black silk. When the white stocking is drawn separately upon the hand, no crackling is heard, nor sparks of fire seen in the dark, let it be pulled backward and forward ever so often: when another white stocking is drawn on above it, nothing more appears: and, when separated from the hand, neither of them discovers any signs of electricity, excepting that, when brought within a few inches of the electrometer, they attract and repel the balls a little.

If instead of two white or two black stockings, one white, and over that, a black stocking be drawn upon the hand, they discover not the least signs of electricity while they continue upon the hand, even tho' they should be drawn backwards and forwards upon it several times; nor, when taken together from the hand, and presented to the electrometer, do they appear to have acquired any more than a very small degree of electricity. They must be brought within the distance of a foot, nay, sometimes of a few inches, before they have any effect upon the balls: but the moment they are separated, they are found to be both of them highly electrified, the white *positively*, and the black *negatively*. The circumstances, that appear the most to merit observation, are as follow:

1°.—When the electrometer is placed on a non-electric, and the black stocking is presented to it at the distance of 3, 4, or 5 feet, according as it happens to be more or less powerfully electrified, the balls begin to be visibly attracted, and when it is brought nearer, they are seen to be agitated in a violent manner. If, instead of the black, the white stocking be presented at the same distances, it is found to have precisely the same effects, attracting and agitating the balls in the very same manner: From whence it appears, that whatever difference there was between the electricity of the black and the white, under other circumstances, they each of them acquire an equal degree of electricity, by being electrified together.

2°.—When the electrometer is supported by glass, and the white stocking is presented to it, it first attracts the balls, and afterwards repels them; when taken away, it leaves them in a repulsive state with regard to each other; when brought back, it repels them as before. If, in place of the white, the black be now presented, the balls are immediately attracted, soon after again repelled, and left once more in a repulsive state with regard to each other. If the white be again presented, the same train of effects takes place as before; and so on, alternately, as in the case of the clear and opaque glass tubes, when excited; the white stocking answering precisely to the clear, and the black to the opaque tube, and acting the one *positively*, the other *negatively*, at full as great a distance, and as forcibly, as the tubes.

3°.—Both the stockings, when held at a distance from one another, appear inflated to such a degree,
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that, when highly electrified, they give the intire shape of the leg; and when brought near the face, or any naked part of the body, there is a sensation felt, as if a cool wind was blowing upon that part. When the two white, or the two black, are held together by the extremities, they repel one another, and form an angle, seemingly of 30 or 35 degrees.

4^o.—When a white and a black stocking are presented to each other, they mutually attract, with a force answerable to the degree of electricity they have acquired: when brought within the distance of three feet, they usually incline towards one another: within two and a half, or two feet, they catch hold of each other; and when brought nearer, they rush together with surprising violence. As they approach, their inflation gradually subsides; and their attraction of foreign objects diminishes: when they meet, they flatten, and join as close together, as if they were so many folds of silk; and then the balls of the electrometer are not affected at the distance of a foot, nor even of a few inches at certain times. But what appears most extraordinary, is, that when they are separated, and removed at a sufficient distance from each other, their electricity does not appear to have been in the least impaired by the shock they had in meeting. They are again inflated, again attract, and repel, and are as ready to rush together as before *.

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* The phenomena, here remarked, of the black stocking and the white when electrified; namely, that, as they approach one another, their attractive and repulsive force decreases, with regard to foreign objects, but increases surprisingly, with regard to each other; and that their electricity suffers no diminution from the shock

When this experiment is performed with two black stockings in one hand, and two white in the other, it exhibits a very curious spectacle: The repulsion of those of the same colour, and the attraction of those of different colours, throws them into an agitation that is not unentertaining, and makes them catch each at that of its opposite colour, at a greater distance than one would expect. When allowed to come together, they all unite in one mass; when separated, they resume their former appearance, and admit of the repetition of the experiment as often as you please; till their electricity, gradually wasting, stands in need of being recruited.

5^o.—When they are separated from one another, they lose their power very soon, much as the excited tube does; but when they are together, they will retain it for an hour or two, and longer, when the air is in a state favourable for electricity. While they are asunder, and any non-electric is brought near them; if that non-electric is of a broad surface, it is with difficulty they are discharged of their electricity; but if the point of any, especially of a metallic body, be presented, they are instantaneously deprived of their electrical virtue: but if they be in conjunction together, they retain their electricity with so much obstinacy, that even the sharpest point of metal cannot deprive them of it. In this, and in some

shock of their congress, appear to me to be observations new in electricity, and to merit attention. They seem to point out a retentive power of electricity, which takes place between electrics and electrics only; and which, I apprehend, may be found to be the cause of many curious and singular phenomena.

other respects, there appears to be such a resemblance between the Leyden phial, or the electrical pane of glass, and the black stocking in conjunction with the white, especially when the one is within the other, that I have been induced to consider them both in the same light. In both cases, the *positive* electricity is on the one side, and the *negative* on the other; and the stockings, as well as the phial, and the pane of glass, are at once electrified *positively* and *negatively*. In both cases there is an accumulation of electricity, and a retention of it, far beyond what is to be met with in a simple body, electric or non-electric. There is, however, a very remarkable difference between them in two respects. In the phial, and in the pane of glass, an explosion is always obtained by carrying on a communication between the two sides by the interposition of a non-electric; but, in the case of the black stocking and the white, I never yet have been able to procure an explosion, nor so much as a speedy discharge, by any means I could think of, while the one was within the other. I have put one hand within the innermost, and with my other have clasped the outward stocking; nay, I have thrust in my hand, and turned the stockings inside out, and, in that condition, have dashed them against the floor; and all this without procuring the least perceptible discharge. On the other hand, the phial and the pane of glass afford no opportunity of separating the *positive* from the *negative* electricity, so as to shew them intire and distinct from each other; whereas we need only pull the stockings asunder, and then in the white we find the *positive*, and in the black the *negative* electricity.

6°.—When the stockings are separated, and in the dark, upon presenting to them the point of one's finger, or any small metallic body, rounded at the end. they exhibit the appearance of electrical fire or light, according to the *negative* or *positive* state of the stocking the object is presented to. With the black, at the distance of two or three inches, there appears to dart from the end of one's finger a sprig or pencil, as it were, of fiery sparks, which dilates in its progress, and strikes against the surface of the stocking: at the same time a crackling, or snapping noise, is heard. When the first discharge is made, upon presenting the finger to a fresh part of the stocking, the same phenomenon is repeated, till you have traversed the whole length of the stocking, which, when the finger moves slowly, usually yields eight or ten distinct discharges, before it is divested of its electricity. With regard to the white stocking, the same appearances hold; but with this difference, that, instead of sparks of fire issuing from the finger, a little globule of white or bluish light is seen at the point of it; and, when the electricity is strong, that little body of light seems to break in an explosion between the stocking and the finger; and rather a hissing than a crackling noise is heard.

7°.—The electrical phial may be charged by the stockings, either *positively* or *negatively*, according as the wire from the neck of the phial is presented to the white or the black; and in the one, or the other case, the hissing, or the crackling noise, is louder than when any common wire, or non-electric body, is presented: but if the electricity of the white stocking be thrown into the phial, and upon that the elec-

electricity of the black, or *vice versa*; in that case, the phial will not be electrified at all.

The charging of the phial was among the first of my experiments with electrified stockings. By some trials I made in the month of December last, I found it would succeed. One frosty evening in that month, having thrown into a small phial, filled with quick-silver, the electricity of one black stocking, I received from the explosion a smart blow upon my finger. With the electricity of two stockings, the blow reached both my elbows; and, by the means of four, I kindled spirits of wine in a tea-spoon, which I held in my hand, and, at the same time, I felt the blow from my elbows to my breast. It may not, however, be improper to observe, that the electricity, in this case, was excited by means of the leg.

From what hath been said in the preceding pages, it is evident, that all the remarkable appearances of electricity, hitherto discovered, may be exhibited by a simple apparatus of black and white silk. But this is not all: in the course of experiments above-mentioned, something curious has occurred to my observation, of which I do not find that any notice has been taken by others.—What I mean is, a strong cohesion produced by electricity. But as this paper is already extended to a great length, I shall reserve the account of electrical cohesion for another, which I shall soon have the honour of presenting to the Society.

New Experiments and Observations concerning Electricity.

P A P E R III.

Of Electrical Cohesion.

Read June 21,
1759. **A**Ccording to what I promised in the conclusion of my last paper, I come in this to give the Society an account of cohesion produced by electricity. I had not made any great progress, in the series of experiments and observations I have already had the honour to communicate, before I perceived that the black and white stocking, when electrified, and allowed to come together, not only joined extremely close, but actually stuck to each other; insomuch that unless when weak in electricity, or improperly applied, I could make the white bear the weight of the black, or the black that of the white, and that for a considerable time. But as the weather, for some months in winter, was so seldom favourable for electrical experiments, that I had scarcely opportunities sufficient to satisfy myself with regard to other points, I did not enter upon an examination of this phenomenon experimentally, till about the latter end of March. By that time, I had got ready the scale of a balance properly fitted with a hook to catch hold of the stocking, a set of Troy-weights I could depend upon, and an exact pair of scales, to take the precise weight of the stockings as occasion should require.

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By experience I found that the same pair of stockings did not always do equally well, even independently of the weather; and that, by being too frequently electrified at a time, their virtue appeared to diminish. I therefore judged it proper to be provided with changes of pairs; and that there might be the greater conformity between the experiments, I chose them as exactly as possible of the same size and substance. The sort I fixed upon, is what is called half gauze; the weight of the white stocking, at an average, 18 *dwt.* and 10 *gr.* but when died black, 1 *oz.* and 1 *dwt.* the weight being increased, by the dying of that colour, above 5 *dwt.* in the pair. When the white and the black stocking were warmed at the fire, so as to be prepared for electricity, they usually lost about a twentieth part of their weight; so that in the course of my experiments I rate the white at 17 *pwt.* and $\frac{1}{2}$, and the black at 1 *oz.* The scale, with the silk lines that belonged to it, and the hook, was adjusted precisely to the weight of 1 *oz.*; and as I commonly measured the strength of cohesion by fixing the hook to the black stocking, and taking hold of the white, I had but to make an allowance of 2 *oz.* more than the weights put into the scale, so as to take the precise weight the stockings could raise by the power of cohesion.

I measured this power two different ways; the first whilst the one stocking was still within the other; secondly, when separated, and the one afterwards applied externally to the other. In the first of these cases, it may be thought that an allowance should be made for the friction in pulling the stockings asunder; but that appeared to me to be very inconsiderable; for
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when those of the same colour were put one within the other, and inverted, they dropped afunder of themselves; or if there was any intanglement about the heel, a little shaking disengaged and separated them: however, if it should be thought proper, the allowance of an ounce may be made, by deducting so much from the weight respectively found.

I have but one circumstance more to mention, before I proceed to give the result of my experiments; which is, that we must not be surprised, when we find the force of cohesion externally, to be in no regular proportion with that within; for when the stockings are highly electrified, they rush together with such impetuosity, that it is extremely difficult to direct their motion, and make them meet in the manner most advantageous for cohesion.

In the experiments I have made, to measure the force of electrical cohesion, I have always found it answerable, so far as I could judge from appearances, to the degree of electricity at the time excited. When the stockings have been but weakly electrified, I have found them unable to support the weight, the one of the other. When in a more powerful state of electricity, I have known them to raise, respectively, from one to twelve ounces, and upwards; nay, once I found the cohesion so strong as to move seventeen ounces, including the scale and the black stocking. For the sake of accuracy, I shall give a particular account of the result of a few of my most remarkable experiments, as I find them in the notes, which I took at the time of making them.

The first I find is of the 30th of March; the wind at north-east; the weather clear, inclining to
 VOL. LI. A a a frost.

frost. The white stocking within the black, raised the weight of 1 *lb.* 1 *oz.* 6 *dwt.* $\frac{1}{2}$, half a pennyweight more separated them. I find no note here taken of the weight born by the stockings applied externally to each other.

April 6. A hazy and wet morning; but the wind at north-east. With new stockings; the white, being within the black, raised 11 *oz.*—without, 6 *oz.* With another pair, that had been much used in experiments; the white, within, raised 6 *oz.*—without, 3 *oz.*

April 16. A clear dry morning; the wind at north-east; Fahrenheit's thermometer at 48. Of the new, the white stocking, within, raised 1 *lb.* 5 *oz.*—without, 6 *oz.* 15 *dwt.*—Of the old, the white stocking, within, raised 8 *oz.*—without, 5 *oz.* 15 *dwt.*—

The last observation I find marked, is of the 19th of May; the weather clear; the wind at north-east; the thermometer at 55. The white, within the black, raised 10 *oz.*—and without, 6 *oz.*

It is to be remarked, that by this time I had got the old stockings washed; and now there appeared little or no difference between the power of them and of the newer pairs; though the latter had still the advantage.

In making the experiments, it was necessary to lose as little time as possible, on account of the waste of electricity: I could therefore seldom proceed to the accuracy of fractions of a penny weight; nor often indeed of those of an ounce; and this is the reason that my notes run generally in round numbers, which, however, may be depended upon.

The

The greatest weight I have been able to raise by the force of electrical cohesion, as appears above, has been seventeen ounces. Now the white stocking, which weighed but 17 *dwt.* and an half, bore all this weight: in this case therefore it raised, by the strength of its cohesion with the black, 340 pennyweight; that is, nearly twenty times its own weight*. And if we consider that the force, applied to separate them, acted in a direction parallel to the surfaces, by which they cohered; and that when the surfaces are smooth, a force acting in such direction, has much greater influence in separating bodies, by making them slide gently over one another, than if those bodies were rigid, and the force employed to separate them acted in a direction perpendicular to the cohering surfaces;

* As the experiments mentioned above were made in the space of six or seven weeks from about the latter end of March, when the temperature of the air begins to be less favourable for electricity, I did not doubt, but upon the approach, and during the progress of the ensuing winter, I should meet with instances of a stronger degree of cohesion, than I had before been able to ascertain. Accordingly, since this paper was read in the Royal Society, and particularly in the months of November, December, and January last, at times, when the weather was clear and frosty, I found that the same stockings lifted considerably more, than I had been able to make them do in the preceding months of March, April, and May. I likewise found, that when the stockings were perfectly new, or the black dyed afresh, and the white newly cleaned and sulphured, as also, that when they were of a more substantial make, such as those that are wove of spun silk, weighing commonly about the double of those that go by the name of half gauze, their power of cohesion, when favoured by the temperature of the air, increases to a very considerable degree. Under those circumstances, at particular times, I have been able to make the black stocking, or the white, when the rough sides of each were put together, raise (the half gauze) from 20 to 40, and (of spun silk) from 40 to 90 times its own weight. Vide the subsequent letter from Dr. John Mitchell to the Rev. Dr. Birch.

when we consider this, I say, it will be hard to determine how great the strength of their cohesion may be.

The experiment may be tried with two plates of glass, the one electrified *positively*, the other *negatively*. As in that case the principle, upon which the cohesion of the white with the black silk depends, would take place, I make no manner of doubt but the effect would be the same. I have not had an opportunity of trying the experiment: but I should expect that the two plates would be found to cohere with greater force, than I have been able to ascertain in the stockings; as a contrivance might be made to pull them asunder in a direction perpendicular to their cohering surfaces.

The force with which the black and the white stocking cohere, is not the only thing remarkable in their junction. The solution of that cohesion, and the different degrees of tenacity, according to different circumstances, afford some curious observations.

When the black and the white stocking are in cohesion with each other, if another pair, more highly electrified, be separated, and presented to the former still in conjunction, the black to the white, and the white to the black; in that case, the cohesion of the first pair will be dissolved, and each stocking of the second, will carry off that of its opposite colour adhering to it. If the degree of electricity of both pairs be equal, the cohesion of the first pair will be weakened, but not dissolved; and all the four will cohere, forming as it were one mass. If the second pair be but weakly electrified, the cohesion of the first pair with one another will be but little impaired,

ed, and that of the stockings of the second with those of the first, will be weak in proportion. And lastly, if the second pair be not at all electrified, or if, in their place, any other body not electrified be presented, there will be no effect produced on either hand.

White silk and black, when electrified, not only cohere with each other in the manner shewn above, but when in a high degree of electricity, are found, both one and the other, to adhere to bodies of broad and even, or polished surfaces, though those bodies be not electrified. This adhesion I discovered accidentally. While I was about some electrical experiments, having, without design, thrown a stocking, that was highly electrified, hastily out of my hand, I was surprised to find it some time after, sticking against the paper-hangings of my room. This led me to make the following experiments.

I presented the white and the black silk, highly electrified, and in cohesion with each other, to the hangings; but no effect was produced. I then separated the black from the white, and presented them singly; in that case each of them readily adhered to the hangings, which they likewise did when flung from a little distance, and continued there for near an hour before they dropped. Having stuck up the black and the white, in the manner above-mentioned, I came with another pair of stockings highly electrified, and applying the white to the black, and the black to the white, I carried them off from the wall hanging on those that had been applied to them. When the second pair were electrified, but to a moderate degree, on applying them, in the manner above described,

described, the former immediately quitted their hold of the hangings, and dropped to the ground. The same experiments held with the painted boards of the room; and likewise with the looking-glasses; to the last of which, both the black and the white silk, appeared to adhere more tenaciously, than to either of the former.

I am afraid I have presumed too much on the patience of the Society, by giving so full a detail of my experiments and observations, on a branch of electricity, that takes its rise from so singular, and so mean a subject as that of black and white silk: But however particular the subject may be, the properties of electricity that are thence experimentally deduced are of a general nature, and must find a place in every true system of electricity. If any apology be wanted, the best I can make, is to endeavour to draw such inferences from the experiments above recited, as may possibly throw new light upon the theory of electricity.

But lest I should swell this paper to too large a size; and as the season is at hand when the Society usually adjourns for some months; I think it best to defer any matter I may have to offer, concerning the theory of electricity, till a convenient time after our next meeting. I shall only beg leave at present, to mention one or two things, which I have not hitherto had a proper opportunity of throwing out.

It hath been said, that the influence of colours in electricity is no new discovery; that Mons. Du Fay had treated at large upon the subject; and, after a variety of experiments, had concluded, that colours, as such, had no effect in electricity; but that whatever

was

was remarkable in that way, was owing to the change, which the ingredients of the dye produced upon the coloured body. I had not then seen what *Monf. Du Fay* wrote upon the subject; but as I have since, I shall take the liberty to state this matter fairly.

The late *Monf. Du Fay*, an ingenious member of the Academy of Sciences at Paris, to whom we owe some valuable discoveries in electricity, gives an account of what is here alluded to, in a memoir, presented in the year 1733. Electricity was at that time in its infancy; *Mr. Hawksbee* had, but a little before, published an account of his experiments; which brought such surprising appearances of electricity to light, as could not but induce the curious to turn their eyes upon that subject. In the course of those experiments, he had taken notice of something remarkable with regard to colours. *Mr. Gray* succeeded, and having opened a new path, made still further discoveries in electricity: he likewise, in giving an account of what he had observed, hinted at something curious with regard to colours. But neither of them appear to have come to any determined point in this matter. *Monf. Du Fay*, who concurred with *Mr. Gray*, in carrying on electrical discoveries, with a candour and ingenuity that did honour to them both, having entered upon an enquiry (the subject of the memoir above-mentioned) to determine what sort of bodies were most susceptible of electricity, thought proper, in consequence of what had fallen from *Mr. Hawksbee* and *Mr. Gray*, to examine what effect the different colours had in augmenting or diminishing the electricity of different substances.

Accordingly

Accordingly he ranged a number of ribbands, of all the primitive colours, hanging them in the same vertical plane; and to these he applied an excited glass tube, in an horizontal direction.—Upon this he observed, that the black was first attracted; and, as he brought the tube nearer, the white next; and the rest successively, though not always in the same order. He made another experiment, in the same view, with gauzes of different colours, through which he tried the force of an excited tube, upon light bodies placed at a proper distance behind them: and from the result he was of opinion, there was something in the influence of colours. But having afterwards tried some experiments with the coloured rays of the sun as refracted by a prism, with flowers of different colours, and with white ribbands rubbed over with differently coloured substances, he began to change his opinion. He likewise had recourse to what he calls a decisive experiment: he dipped his different-coloured ribbands in water; and when they were all equally wetted, he applied his tube, and found they were all equally attracted. From this last-mentioned experiment, in particular, he concluded that colours, as colours, had no effect in electricity; but that all was owing to the ingredients of the dye imbibed by the coloured body.

It is not my purpose here to inquire, whether Monf. Du Fay's conclusion is well or ill founded. Whatever may be the decision of that point, I apprehend the whole of this affair hath very little concern with what hath been the subject of these papers, and could have been of little use to me, had I been acquainted with it before.

The

The series of my experiments, however inconsiderable they may prove in the result, have taken a turn I did not at first foresee. I set out with inquiring into the nature of an electricity, that seemed to have some connexion with the human body: I had made but little progress when I was surpris'd with an appearance of electricity, arising from the contrast of two colours, or coloured bodies of the same substance: I met with it in my experiments, perpetually *positive* and *negative*; and under that appearance have followed it through a variety of its operations. The notions it hath led me to conceive, are different from those I had before entertained of electricity. Such as they are, they shall, in due time, be freely submitted to the judgment of the Society.

Having been told by one or two of my friends, that they had tried some of the experiments mentioned in the preceding papers, but could not get them to succeed; I beg leave to add a few words, before I conclude, by way of caution to any, who may have a curiosity to verify my experiments.

However easy it may seem to be, to follow the directions I have already given in electrifying the stocking, I am sensible from my own experience, that an attention to a number of little circumstances, besides some small degree of address, is requisite, in order to make it succeed readily. This is known to have been the case with the electrical tube and globe: few people, at first, knew how to manage them successfully; and yet glass is not so much expos'd to many inconveniencies, that affect electricity, as silk. To give but one instance of this: we know that a very small quantity of dust, grease, or any other matter that

sticks to the tube, will injure its electricity: Now this is what may easily be wiped off from glass; but it may be very difficult to clear the silk of it, as silk is of a nature more apt to imbibe, and to retain extraneous matter than glass.—From these considerations, I should not be surpris'd at any persons being disappointed, as to the success of their experiments, in a few trials; but I should think it not fair for them to conclude from thence, that those above-recited are not to be depended upon*. Yet, if any member of the Society, who is curious in these matters, hath not been able to satisfy himself with regard to any particular experiment, I shall think it no trouble to shew him, at any proper time, how it succeeds with me.

* The circumstances necessary to be attended to, in order to procure the most considerable appearance of electricity, are as follow. 1°. That the wind be in the north, north east, or east; the weather clear and frosty, or inclining to frost. 2°. That the stockings be of silk; one of a good black, the other of a clear white; and both of the same size and substance. 3°. That they be new; or be kept carefully wrapt up in paper, and only used in electrical experiments. 4°. And lastly, That they be dried before the fire, and warmed to about the degree of heat of the human body, before they be drawn upon the hand or leg. And when taken off, care should be had in separating them, so as to keep them at a distance from one's clothes, or any thing that may lessen their virtue. The circumstances above-mentioned, might be gathered from what has been said in these papers; but I thought it not amiss to bring them together in this note.

*New Experiments and Observations concerning
Electricity.*

P A P E R I V . P A R T I .

Of Two distinct Powers in Electricity.

Read Dec. 20, 1759. **I** Observed, in the papers I have already had the honour of communicating to the Society, that the different state of electricity, as distinguished into *positive* and *negative*, was a leading circumstance in all electrical appearances; and that, if followed out with due attention, it might bring us to a clearer view, than we yet have had, of the powers that nature employs in those wonderful operations. Nothing could be more proper to serve this purpose, than the simple apparatus I had all along made use of. It consisted of two electric bodies, of which, when they were excited, one never failed to assume the positive, the other the negative state of electricity. The observations I had frequent opportunities of making, with regard to the manner in which they acted, in these different states, on other bodies, and on each other reciprocally, confirmed me in a notion, which, in the course of my experiments, I had very early conceived.

My notion is, that the operations of electricity do not depend upon one single positive power, according to the opinion generally received; but upon two distinct, positive, and active powers, which, by contrasting, and, as it were, counteracting each other,

produce the various phenomena of electricity; and that, when a body is said to be positively electrified, it is not simply that it is possessed of a larger share of electric matter than in a natural state; nor, when it is said to be negatively electrified, of a less; but that, in the former case, it is possessed of a larger portion of one of those active powers, and in the latter, of a larger portion of the other; while a body, in its natural state, remains unelectrified, from an equal ballance of those two powers within it.

I do not here undertake to give a system of electricity. It is the design of this paper to propose the grounds of my opinion, only so far as it rests upon observation and experiment. If the proofs I have to offer shall be found conclusive, and it be allowed, that two distinct and counteracting powers prevail in electricity, one of them corresponding with the positive, and the other with the negative state; in that case, the truth thus established, may afterwards be assumed as a principle in theory; and we may try how far it will serve in accounting for the various appearances of electricity. But even then, I should not think of troubling the Society with discussions of so great a length, and of so speculative a nature, as those usually are that relate to theory.

I might bring arguments to prove the existence of two distinct powers in electricity, from a variety of observations and experiments, some of them taken from among those mentioned in the preceding papers: But as the bounds I prescribe to myself in this, do not permit me to enter upon so large a field, I shall confine myself to such observations only, as have fallen within

within my notice, in one particular branch of electricity, that which relates to the Leyden phial.

All who allow of *positive* and *negative* electricity, know, that the phial, when charged, exhibits electricity in those two states, the one within, the other on the outside; and that when a communication is made between the two, by the means of a non-electric touching the coating, and at the same time approaching the wire, or *vice versa*, the explosion is produced, and the phial discharged. This reduces the question to a narrow compass; for if, upon the discharge of the phial, we meet with proofs not only of a power acting from within to the outside, but also of a power acting at the same instant from the outside to within, then, I think, we may fairly conclude, that what is called *negative* electricity is, in reality, a positive active power; and that electricity, in general, consists not of one alone, but of two distinct, positive powers, acting in contrary directions, and towards each other.

The proof I shall offer first, is founded on the following experiment. When the phial is electrified but a little, if we touch the coating of it with a finger of one hand, and at the same time approach a finger of the other hand to the wire, we shall receive a pretty smart blow upon the tip of each of the fingers, the sensation of which reaches no farther: If the phial be electrified a degree higher, we shall feel a stronger blow, reaching to the wrists, but no farther: When again it is electrified to a still higher degree, a severer blow will be received; but will not be felt beyond the elbows: Lastly, when the phial is strongly charged, the stroke may be perceived in the wrists and elbows;
but

but the principal shock is felt in the breast, as if a blow from each side met there. This plain and simple experiment seems obviously to suggest to observation, the existence of two distinct powers, acting in contrary directions : And I believe it would be held as a sufficient proof by any who should try the experiment, with a view to determine the question simply from their own perceptions.

But as I am sensible, that the proof of any important point in philosophy, ought not to depend upon the perceptions of this or that particular person, I judged it necessary to have recourse to experiments, the result of which might admit of no ambiguity. The fortunate discovery of M. Muschenbroek and M. Allamand, with the improvements that have since been made upon it, puts it in our power to increase electricity to what degree we please. I did not therefore despair of the means of bringing this matter to a fair decision. I expected, that if an electrical stroke should be made to pass through a solid body, with so much force as to pierce and tear the substance of it, such marks would be left, as might enable us, with certainty, to trace the course of the electrical power in its passage through the body.

Having no apparatus of my own capable of producing such effects, I had recourse to a worthy member of this Society, doctor Franklin, who was possessed of a very good one. I had communicated all my observations to this gentleman as they occurred, and, in return, met with an ingenuity and candour, that render him as estimable in private life, as the improvements he has introduced into electricity, and particularly his discovery in relation to thunder
and

and lightning, will render his reputation lasting in the learned world. We differed in opinion with regard to the point in question; nevertheless I found him ready to give me all the assistance in his power, for bringing the matter to a fair decision. I had seen him pierce a quire of paper with a stroke of electricity; and as I perceived it had been struck several times before, I desired he would give it me, that I might at leisure examine the effects of the sundry strokes.

When I came to do so, I observed, that at every hole which had been made through the quire, the upper and the under leaf (for the quire had been laid in an horizontal position when it was struck) were ragged about the orifice, and those ragged edges pointed mostly outwards from the body of the quire. But what was more material; when I came to turn over the leaves, I found, that the edges of the holes were bent regularly two different ways (and more remarkably so about the middle of the quire), one part of each hole upwards, and the other part downwards; so that, tracing any particular hole as it traversed the quire, I found on one side the fibres pointed one way, and on the other side the other way; much in such a manner, as if the hole had been made in the quire, by drawing two threads in contrary directions through it.

This was not all: A piece of paper, covered on one side with Dutch gilding, had been accidentally left between two leaves in the quire, and had been pierced by two different strokes. This exhibited a very remarkable appearance: Where each of the strokes had been given, the gold leaf was stripped off, and had left

left the paper bare for a little space, in an oblong form, rounded at the ends; in which, at the distance of about a quarter of an inch from each other, appeared two points, one of them a little round hole, the other only an indent or impressiion, such as might have been made by the point of a bodkin. In the leaf, which fronted the gilding, two such points likewise appeared, corresponding to those above-mentioned; so that the hole in the one was opposite to the impressiion in the other, but surrounded with little black or blueish circles. When the hole, which had been struck in the quire, was traced from above down to the gilding (for the gilt paper happened to lie with its gilded side uppermost), it was found to terminate on the point in the gilt paper where the impressiion appeared, and there the impressiion pointed downwards. Again, when the hole in the lower part of the quire was traced from below upwards, it was found to terminate on the point in the leaf fronting the gilding, where the impressiion was, and there the impressiion pointed upwards. The facts above-mentioned seem to leave it without doubt, that the stroke had been given, at the same instant, upwards and downwards; but that the electrical power from above, and from below, had seized upon the gilding, dissipated part of it in vapour, and by that means become so weak, that each of them could afterwards only make an impressiion upon the paper, marking the respective directions of their course.

I communicated these observations to Dr. Franklin; but as no conclusion can, with certainty, be drawn but from facts, confirmed by repeated trials, I desired to have the satisfaction of making a few experiments

riments with him in relation to this matter ; to which he readily consented. For that purpose I waited upon him one morning about the middle of June last ; and the better to ascertain what was essential in the facts, I varied the circumstances a little from those above.

In the middle of a paper-book of the thickness of a quire, I put a slip of tin-foil ; and in another of the same thickness I put two slips of the same sort of foil, including the two middle leaves of the book between them. Upon striking the two different books, the effects were answerable to what I expected. In the first, the leaves on each side of the foil were pierced, while the foil itself remained unpierced ; but, at the same time, I could perceive an impression had been made on each of its surfaces, at a little distance one from another ; and such impressions were still more visible upon the paper, and might be traced as pointing different ways. In the second, all the leaves of the book were pierced, excepting the two that were between the slips of foil ; and in these two, instead of holes, the two impressions, in contrary directions, were very visible.

I have lately got an electrical apparatus of my own, formed on the model of that of Dr. Franklin's, and have had opportunity since, of making frequent repetitions of the experiments above-mentioned. Notwithstanding some little variation in appearances, arising, as in other electrical experiments, from the particular state of the weather, the different degree of electricity, or other accidental circumstances, I have met with nothing but what confirms me in my opinion of two distinct counteracting powers. All

the remarks I have been able to make in the repetition of experiments, that need to be added to what I had before observed, may be reduced to the three following.

1°. When a quire of paper, without any thing between the leaves, is pierced with a stroke of electricity, the two different powers keep in the same tract, and make but one hole in their passage through the paper: not but that the power from above, or that from below, sometimes darts into the paper at two or more sundry points, making so many holes, which, however, generally unite before they go through the paper. What I mean is, that I never yet could observe the two powers to make different holes in the paper; but that they always keep the same common channel, rushing along it with inconceivable impetuosity, and in contrary directions. They seem to pass each other much about the middle of the quire; for there the edges are most visibly bent different ways: whereas in the leaves near the outside of the quire, the holes very often carry more the appearance of the passage of a power issuing out, and exploding into the air, than of one darting into the paper.

2°. When any thin metallic substance, such as gilt-leaf, or tin-foil, is put between the leaves of the quire, and the whole struck; in that case, the counteracting powers deviate from the directest tract, and leaving the path they would in common have taken through the paper only, make their way in different lines to the metallic body, and strike it in two different points, distant from one another about a quarter of an inch, more or less (the distance appearing to be least when the power is greatest;) and whether they
 pierce,

pierce, or only make impressions upon it, in either case, they leave evident marks of motion from two different parts, and in two contrary directions. It is this deviation from a common course, and the separation of the lines of direction consequent upon it, that affords us the strongest proof, of the exertion of two distinct and counteracting powers.

3^o. When two slips of tin-foil are put into the middle of the quire, including two or more leaves between them, if the electricity be moderately strong, the counteracting powers only strike against the slips, and leave their impressions there. When it is stronger, we generally find one of the slips pierced; but seldom both: and from what I have observed in such cases, it would seem as if the power, which issued from the outside of the phial, acts more strongly than that which proceeds from within; for the lower slip is most commonly pierced: But that may be owing to the greater space, the power from within has to move through, before it strikes the paper.

I take the liberty to lay before the Society a paper-book, of the thickness of a quire, struck three times in the manner above described. The first stroke (A) is given, when there is nothing between the leaves of the book. The second (B) when a piece of paper, covered on one side with what is commonly called Dutch gilding, is laid in the middle. The third (C), when two slips of tin-foil are put into the book, including the two middle leaves between them.

The members, who are curious in these matters, may, at their leisure, examine the effects of the sundry strokes; and if any gentlemen, in particular, desire the farther satisfaction of seeing the strokes given,

I shall be very ready, at any proper time, to comply with their desire.

New Experiments and Observations concerning Electricity; by Robert Symmer, Esq; F. R. S.

P A P E R IV. P A R T II.

Of Two distinct Powers in Electricity.

Read Dec. 20, 1759. **T**HE notion of two distinct electrical powers, acting in contrary directions, may appear to some to be the same with that of the *effluence* and *affluence* of electrical matter, which M. l'Abbé Nollet gives as the general cause of the phenomena of electricity *. It may therefore be not improper to take a nearer view of these two opinions, to see how far they agree, and in what they differ.

This ingenious author, whose merit in the learned world is very considerable, particularly with regard to his labours in electricity, had observed, that, when a body is electrified, a current of electric fluid issues from it, and, in the form of diverging rays, spreads through the air, and enters into other bodies; and that, at the same time, a current of electric fluid,

* “ Plus de trois ans se sont écoulés depuis que j'ai proposé
 “ comme la cause generale des phénomènes électriques, *l'effluence*
 “ et *l'affluence simultanées d'une matiere fluide, presente par tout, et*
 “ *capable de s'enflammer par le choc de ses propres rayons.*” Preface
 to *Recherches sur l'électricité*, at the beginning.

issuing from other bodies, passes through the air, and, in the form of converging rays, enters into the body electrified. From thence he concludes, that a continued, and (to use his own terms) simultaneous * effluence and affluence of a fluid matter, extremely subtile, constitutes † electricity. Upon this principle he endeavours to account for all the phenomena that attend the electrification of bodies.

What M. l'Abbé Nollet has observed with regard to two contrary currents in electricity, is by no means inconsistent with the principle of two distinct counter-acting powers. On the contrary, the existence of two such currents is, according to my opinion, a necessary consequence of the exertion of those powers from one body upon another. It is a phenomenon of electricity only; not the principle upon which all electrical appearances depend.

But a more essential difference takes place between this gentleman's opinion and mine: he represents the two currents as consisting but of one and the same

* " Ces deux courans qui ont des mouvemens opposes, ont lieu tous deux ensemble, c'est ce que j'exprime par le mot simultané." *Lettres sur l'électricité*, p. 30.

† " L'électricité, comme je l'ai déjà dit et prouvé ailleurs, n'est pas seulement l'émanation d'une matiere qui s'elance du corps électrisé; c'est aussi un remplacement continuel qui se fait de cette matiere, par une autre tout-a-fait semblable, qui se porte de toutes parts au corps électrisé; c'est pour ainsi dire, un commerce de la matiere qui j'ai nommée effluente, et de celle que j'ai appelée affluente. Si celle-ci vient à manquer, ou que la premiere n'ait plus la liberté de sortir, cet état ou ce double mouvement, que l'on nomme *électricité*, doit bien-tot cesser." *Essai sur l'électricité*, p. 202.

fluid †; admits but of one kind of electricity ||; and maintains, that two bodies cannot be said to be differently electrified, but as they are electrified in a higher or lower degree *. On the other hand, it is my opinion, that there are two electrical fluids (or emanations of two distinct electrical powers) essentially different from each other; that electricity does not consist in the efflux and afflux of those fluids, but in the accumulation of the one or the other in the body electrified; or, in other words, it consists in the possession of a larger portion of the one or of the other power, than is requisite to maintain an even ballance within the body; and, lastly, that according as the one or the other power prevails, the body is electrified in one or in another manner.

In those respects we differ in opinion. Who is in the right is another question. The whole seems to turn on a single point, namely, whether there be but one, or if there are two distinct kinds of electricity. The bounds of this paper do not permit me to enter upon a full discussion of the point. I cannot, however, but observe, that the whole series of experiments mentioned in the preceding papers, tends to confirm the distinction, formerly made, of electricity into two kinds; and to shew, that there is an essential difference (whatever it be that constitutes that difference) between what is commonly called positive electricity, and negative. A farther proof of that difference arises from the success of an experiment, of

† *Essai sur l'électricité*, p. 160, 161.

|| *Ibid.* p. 118, 119.

* *Lettres sur l'électricité*, p. 101. 105.

which I threw out a hint in my third paper, and which I have since taken an opportunity of making, touching the electrical cohesion of glass. The experiment is as follows :

I took two panes of common window-glass, about nine inches square, the thinnest, the most even, and the smoothest in their surfaces I could get. I covered one of the sides of each with tin-foil, leaving the space of near an inch from the edges uncovered. I warmed them a little at the fire ; and, applying the two bare sides together, I laid them upon four wine-glasses, which supported them at the corners. I then brought down a chain from the prime conductor, nearly to touch the coating of the upper plate, and applying a wire, which I held in my hand, to the coating of the under plate, the machine was put in motion, and the electrification performed, as in the case of the common electrical pane. When the operation was completed, I removed the chain and the wire, and taking hold of two opposite corners of the upper glass (those corresponding to them in the other having been purposely cut away, I lifted it, and found, that the under glass came up with it. The cohesion appeared to me to be considerably strong ; but I had not any proper apparatus ready to measure the strength of it. I laid them down again on the wine-glasses, and procured an explosion, as in the case of the common electrical pane. I then took hold of the corners of the upper glass, and lifted it ; but found, that the cohesion was dissolved, the under glass remaining behind.

I could indeed perceive, that, after the discharge, there was still some small degree of cohesion between the plates, which felt as if some glutinous substance
had

had got feeble hold of them : but this was no more than what I found took place between them, when, without being electrified, they were forced close together. For that reason, two plates of glass, finely polished, and so even as to come into close contact through the whole extent of their opposed surfaces, would be very improper for this experiment ; for, when the power of electricity had forced them into contact, the pressure of the air, and a cohesion proceeding from another principle, would keep them together.

But to pursue the purpose of our experiment.—All who admit of the distinction of electricity into two kinds, agree, that as in the Leyden phial, so likewise in the electrical pane, the different sides are differently electrified : That side, which more immediately receives its electricity from the glass globe, is said to be positively, and the other negatively, electrified. What may be said of the electrical pane, is applicable to the glass plates in this experiment ; for, when they are put together in the manner mentioned above, they form an electrical pane between them ; one of the plates corresponding with one of the sides, and the other with the other side of the pane. When, therefore, the glass plates are electrified in the manner before described, the plate, which receives its electricity immediately from the chain, will, according to this distinction, be positively electrified, and that which receives its electricity from the wire, negatively.

Upon these considerations, we may expect, from the experiment in hand, the means of determining, whether the distinction of electricity into two different kinds is merely nominal, or if there is an essential difference

difference between them : For after the glass plates have been electrified in one position, so as to be incapable of receiving any more electricity, if they be inverted, and in that new position presented to the chain and wire, and the globe again be put in motion, according as one or other of those opinions holds, correspondent effects will follow. If the electricity, that comes by the chain, be of the same nature with that which comes by the wire, no change will be produced upon the plates ; for being before full of one and the same kind of electricity, they can do no more than keep what they had, or exchange it for just as much of the same kind. But if, by the chain and the wire, two kinds of electricity, totally different in their nature, be conveyed into the respective plates, in that case it is to be expected, that the electricity that each of them had acquired in their former position, will be gradually destroyed, till no signs of electricity appear in either ; after which, they will begin again to be electrified, having their electricity reversed.

In order to see what would really happen, I repeated the experiment in the following manner : I electrified the two plates till they were fully charged, and in strong cohesion, the snapping from the chain and the wire having totally ceased. I then turned them upon the glasses that supported them, applied the chain and the wire to the different sides, and began to electrify as before. The glass globe was no sooner in motion, than the snapping from the chain and the wire returned with violence ; and the plates, which, in the former position, would receive no more electricity, appeared, in their new situation, to receive

it both from above and below, more greedily than ever. As this new electrification proceeded, I found, by several trials, that the cohesion became gradually weaker, till, at a certain period, it was totally dissolved; from which, it began again to be restored, and at last, when the snapping ceased, I found it to be as strong as before.

I carried the experiment still farther: I took two complete electrical panes (that is, two glass plates, covered each on both sides with tin-foil), and laying one upon the other, I applied the chain and the wire, and proceeded to electrify. The electrification took place throughout; and I could procure an explosion from either of them single, or from both together: but however highly they were electrified, I never could perceive the least appearance of cohesion between them. This was agreeable to what I expected. I judged, that, in consequence of two different kinds of electricity, each of the panes would be charged, on its different sides, with the different kinds; which, by counteracting one another in the same pane, would reduce it to a neutral state of electricity, and by that means prevent the two panes from acting on each other.

It is not here my purpose to account for electrical cohesion; yet I cannot but observe, that, in this case at least, it is obvious, that the cohesion cannot be owing to an *effluence* and *affluence* of one and the same electrical fluid: For the two plates being of the same substance, and in every respect alike, the effluent current must have just as great an effect in separating them, as the affluent can have in bringing or keeping them together. The experiment above seems to
make

make it evident, that there are two distinct kinds of electricity; and the influence of those in making the plates cohere, seems naturally to denote, in concurrence with the experiments mentioned in the former part of this paper, two distinct and counteracting powers, corresponding with the two different kinds of electricity.

If, upon the whole, the arguments I have brought to prove the existence of two distinct powers in electricity, are found to be conclusive, it may, perhaps, be expected of me to say something of the nature of those powers. Without entering into any particular theory, or indulging myself in loose conjecture, I shall take the liberty to offer a few considerations, such as occur to me on this occasion.

All we know of active powers, extends no farther than as we perceive them to be effects of a power still more general; or as we find them producing effects according to certain laws. I have not been able to trace the powers of electricity farther back, than the observations I have given above, have led me. I do not therefore take upon me to determine, whether they consist of the finer parts of matter, constituting an active and elastic fluid, the elasticity of that fluid remaining still to be accounted for; or if they are of a substance yet more subtile and active, of which, however, we have hitherto been able to form no distinct idea. Whatever other power they may be the immediate effects of, or whatever be the secret and imperceptible manner in which they act, the more interesting object of our inquiry, is to know the laws according to which they act, and how far their operations extend in the material world.

The same observations that lead us to the discovery of any power, if followed out with due attention, may serve to instruct us in the laws of its action ; and if we can attain a sufficient knowledge of those laws, however ignorant we may be of the peculiar manner in which the power exerts itself, we may be, by that means, enabled to trace it through its various operations.

The laws of nature are few and simple. It is only from the variety of circumstances, under which the respective powers are exerted, that the phenomena of nature are multiplied. The powers of mechanic motion, those I mean by which bodies act upon one another in impulse or pressure, are found to be under the direction but of three general laws ; and from thence is deduced a most extensive branch of natural knowledge.

The laws that regulate the powers, by which bodies act at a distance upon one another, when we come to be better acquainted with them, may be found to be not more numerous or complex. What appears wonderful to us, is, that bodies should at all be capable of acting upon one another at a distance : But are we not equally ignorant of the manner, in which the powers of motion are exerted, when the bodies are in actual congress ? Daily experience convinces us of the fact in this case ; and in the other, repeated experiments, and frequent observations, leave us little room to doubt, that there are powers, which, when lodged in one body, are capable of being exerted upon another at a distance.

The powers of electricity are found to be of this nature. When either of those powers prevails in a
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body,

body, it exerts its influence, so long as it is lodged there, every way around, and, by pressure or otherwise, acts upon another body within the sphere of its influence. If it meets with no resistance, it enters this other body, and from this begins to act, as it did from the former. In the mean while, the counteracting power prevailing in this other body, the like effects will be produced: and thus these two bodies, by means of their corresponding powers, will continue to act upon each other, till their powers be reduced to an equal ballance.

Did electricity consist but of one power, after an experimental inquiry into the laws according to which it acted, we might, upon that principle, be able to account for the phenomena of electricity. But if two distinct and counteracting powers prevail, as appears to me to be evident from the preceding experiments and observations, in that case, it will be impossible to give a complete and consistent theory of electricity, but upon the principle of two such powers. Nor will this principle be found, upon due consideration, to disagree with the general system of nature. It is one of the fundamental laws of nature, that action and re-action are inseparable and equal. And, when we look around, we find that every power, that is exerted in the material world, meets with a counteracting power, that controls and regulates its effects, so as to answer the wise purposes of Providence.

A Letter to the Reverend Dr. Birch, Secretary to the Royal Society, concerning the Force of electrical Cohesion.

S I R,

Read Dec. 20.
1759.

I Happened to be at Mr. Symmer's on Saturday the 15th instant, when he desired me to be witness to some electrical experiments, he was about to make, with silk stockings, of a particular kind, which he had received for that purpose.

The weather was then remarkably favourable for electricity, being clear and dry, with a sharp frost, which had continued five or six days. The wind was easterly, and had been in that quarter for ten days. It was about noon when we made our experiments; the barometer at 30, and Fahrenheit's thermometer at 32.

The stockings above-mentioned were wove of carded and spun silk, and were more substantial and weighty, than those with which he had made the experiments mentioned in his third paper. One pair was of a deep black, having been twice dyed, in order to improve the colour. Another pair was of the natural colour of the silk, of a dusky white; and both new. The pair of black weighed four ounces, eight pennyweight, and four grains; and the white three ounces, eighteen pennyweight, and fifteen grains.

We began with making a few experiments with the thin stockings formerly made use of; and found the result to be much the same with what is related

by Mr. Symmer in his third paper: that is, we found, that when the white stocking was put within the black, or *vice versa*, and both highly electrified, taking hold of the one, while a scale with weights was put to the other, we could raise seventeen ounces before the stockings separated.

We then repeated one or two of those experiments with some little variation of circumstances. We turned one of the stockings inside out, and put that within the other: the inner or rough sides of the stockings being thus together, by which means they took faster hold of each other, we now found, that it required the weight of twenty ounces to separate them.

When the stockings were separated, and applied externally to each other, they then raised the weight of ten ounces *.

We

* Some time after this letter of Dr. Mitchell's had been read in the Society, as I was of opinion, that the thin stockings, mentioned above, had lost much of their electrical power since the beginning of April last, when they first had been made use of in experiments, and that it was owing to the peculiar influence of the weather, that they raised as great a weight now as they had done then, I had the black new dyed, and the white washed, and afterwards whitened in the fumes of sulphur. Upon this, I found their force very much increased. On the 9th of January, the weather being much in the same state as it had been the 15th of the preceding month, the stockings, thus prepared, and put one within another, having their rough sides together, lifted no less than three pounds and three ounces before they separated. Dr. Mitchell was likewise present at this experiment.

How far the circumstance of smoking the white stocking in the fumes of sulphur, might have contributed to increase the electrical power, is what I cannot take upon me to say. I should think, however, that it does not much contribute to it; for we find, by the experiments in the sequel of this letter, that the force of cohesion

We next proceeded to try the force of electrical cohesion, with the stockings of a more substantial make ; viz. those I have above described ; and there we found it to be much more considerable, as appears by the following experiments.

1^o When the white stocking was put within the black (without either of them being turned inside out), so that the outside of the white was contiguous to the inside of the black, they lifted nine pounds, wanting a few pennyweight. Now, taking the weight of the stocking to be one ounce, eighteen pennyweight, and fifteen grains (viz. the half of the weight of the pair as mentioned above), it follows, that, by the force of its cohesion with the black, it raised fifty-five times its own weight.

2^o. When the white was turned inside out, and put within the black, their inner or rough sides being contiguous, they lifted no less than fifteen pounds, one pennyweight and a half, before they separated : So that, in this case, the single stocking raised ninety-two times its own weight †.

sion is surprisngly great between the black and the white stocking of spun silk, when electrified : and yet I was assured by the hosier, that the white had never been put into the fumes of sulphur ; and that the colour it had was the natural colour of the silk, no other method having been taken to whiten it, than that of scouring and washing.

† Since that time, I have not been able to raise above ten or eleven pounds with these stockings, even when the weather has been most favourable ; owing, perhaps, to my having cut off all the ends of threads, and tufts of silk, which had been left on the inside of the stockings ; which I did with a view of increasing the cohesion : whereas, when the inner sides of the stockings were put together, those ends of threads, and tufts of silk, by joining intimately with those of the different colour, probably contributed much to produce that powerful cohesion.

3°. When the inner stocking was drawn out, and applied to the outside of the other, they lifted one pound and three quarters; that is, between ten and eleven times the weight of the white stocking *.

It is not my design to draw any conclusions from these experiments, and much less to determine how far electrical cohesion may serve, as a principle, to account for many remarkable appearances in nature. I relate the experiments I have been witness to, by way of supplement to Mr. Symmer's third paper; and I consider the result of them, only, as a farther proof of the surprising degree, to which a power in electricity, which had not before been attended to, may be carried, in even the slightest substances, those of white and of black silk. I am, Sir,

Your most obedient, humble servant,

Kew, December 18, 1759.

John Mitchell.

* In the third of these papers I observed, that stockings electrified, and applied to one another externally, cohered with a force greater or less, according to the manner in which they joined in contact with each other. This appears to be the reason, why the stockings here made use of, being much less pliable than the thinner kind, do not, in external cohesion, raise a weight so great in proportion as those do. From thence I fancied, that if the stockings of spun silk should be first allowed to come together, and afterwards be pressed close between one's hands, their cohesion externally with one another would thereby be much improved: Accordingly, upon repeated trials, I found, that the white stocking, when thus pressed to the black in external contact, was capable of raising between three and four pounds; that is, about twenty-two times its own weight.

I have taken the liberty to subjoin these few observations, by way of notes, to Dr. Mitchell's letter, as they relate to the same subject, and contain matter, which has occurred since his letter was read in the Society.

February 1st, 1760.

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R. Symmer.

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